Mathematics for next generation radio chips

Collaborative research links academic and industry partners…

European researchers of the ICESTARS (Integrated Circuit/EM Simulation and Design Technologies for Advanced Radio Systems-on-chip) project ensure that future demand for higher capacity communication channels are met by addressing the critical issues of the existing infrastructure for design and simulation of new and highly-complex Radio Frequency (RF) front ends operating beyond 10 and up to 100 GHz.

A foray into the high frequency broadcast spectrum

Recent years have seen a phenomenal growth in the field of mobile devices with products combining analogue and digital parts to enhance transceiver functionality for radio, GSM emitting for phones that, in addition, offer additional functions such as sensors and cameras. Traditional RF design approaches no longer meet the challenges of next-generation communication products. "Within the frequency bands of approximately 1 to 3 GHz used today, it is impossible to realise extremely high data transfer rates," Jan ter Maten from Dutch NXP Semiconductors outlines the ICESTARS starting point. "The channels beyond 10 GHz are of huge economical interest as that is where future wireless devices will operate. We expect to provide the instruments needed for the production of low-cost wireless chips that can operate in a frequency range of up to 100 GHz."

Collaborative research

Funded from the ICT strand of the EU's Seventh Framework Programme (FP7), mathematicians and engineers cooperate on new mathematical developments to be implemented in next-generation single-chip high-GHz wireless modules. The ICESTARS consortium comprises five academic partners (University of Cologne and Bergische Universität Wuppertal, Germany; Hagenberg Upper Austria University of Applied Sciences; University of Oulu and Aalto University, Finland) and four industrial partners (NXP Semiconductors, The Netherlands; AWR-APLAC Corporation, Finland; MAGWEL, Belgium and Infineon Technologies, Germany).

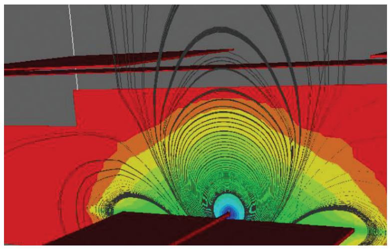
'The channels beyond 10 GHz are of huge economical interest as that is where future wireless devices will operate.'

Mathematics for the RF designer's tool chest

Roughly speaking, the mathematical part in integrated circuit (IC) design (ICs being miniaturised and complex electronic circuits) refers to the physical mapping of the devices. Equations are used to describe the various relations, eg. positioning, geometry and wiring of electronic components, non-linear behaviour (transistors), responses in time and frequency domain, inductive coupling and tuning of oscillators. Miniaturisation has put components close to each other. The overall designs are mathematically complex and call for a lot of electromagnetic coupling.

Mathematical equations such as ordinary differential equations (ODEs), differential-algebraic equations (DAEs) and partial differential equations (PDEs) are core to simulate and predict the behaviour of the designed integrated circuits before the expensive manufacturing process starts.

Protruding into RF design in super high and extremely high frequencies (SHF and EHF, ie. beyond 3 GHz) necessitates an ever increasing miniaturisation of all components. That is where the ICESTARS research focus is situated. Today's SHF and EHF RF designs are functionally not adequate as accurate simulations of such systems are either inefficient or not available. Only a new generation of transceiver architecture and related computer-aided design (CAD) tools will ensure the realisation of such complex nanoscale designs. It necessitates both new modelling approaches and new mathematical solution procedures for differential equations with largely differing time scales, analysis of coupled systems of DAEs and PDEs plus numerical simulations with mixed analogue and digital signals.

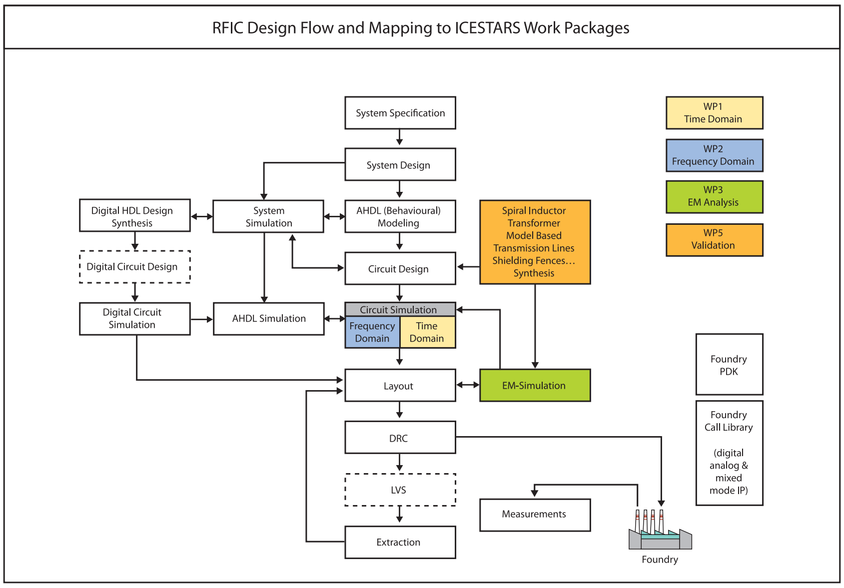


Magnetic field simulation

Time and frequency

In a joint effort the ICESTARS project team aims at an efficient connection between the frequency domain, where the RF part of the wireless transceiver system is designed, with the time domain, where the digital signal processing and control logic are developed.

One of the typical time domain problems the ICESTARS mathematicians are going to solve: with the carrier signal being high frequency and the signal transfer taking place in low frequency spectrum, we are dealing



RF design flow: highlighted are the areas to which the ICESTARS work packages contribute

with different time scales. Hence, novel numerical proceedings are needed to both enable the transfer's quality and model the circuit. One already well known technique to 'split' the envelope from the modulation by the carrier is Equivalent Complex Baseband (ECB). But ECBs cannot be applied to nonlinear differential equations. Therefore, in ICESTARS multirate partial differential equations (MPDEs) are employed. Such multirate models are able to decouple the widely separated time scales of RF signals with the multirate solutions allowing the exact reconstruction of corresponding time-dependent signals.

> 'Within the frequency bands of approximately 1 to 3 GHz used today, it is impossible to realise extremely high data transfer rates…'

The next important ICESTARS field of work is frequency with the partners improving existing and developing new frequency-domain algorithms to provide RF designers with the most effective simulation tools at millimetre wave frequencies with the developments focusing on scalable algorithms for RF design. Scalability in general is studied and applied to enable RF simulations for large circuits, with scalable fast linear solver techniques being central. Additionally, the algorithms used in Harmonic Balance and its noise analysis will be optimised for different types of circuits and available computational resources using the most accurate initial frequency estimates.

Electromagnetic (EM) analysis and coupled electromagnetic circuit analysis mark the third ICESTARS research ground. Here, in principle, we deal with the 'communication' of physical and mathematical layer. The mathematicians supply the electromagnetic circuit simulation to be coupled with the components' simulation software of an industrial partner. The ever increasing miniaturisation of future circuits realised in physical models necessitates the simulation of electromagnetic circuits – an entirely new mathematical undertaking. In ICESTARS it is realised by coupling electromagnetic simulation to DAE-solvers for transient simulation.

Real-life simulation

As proof of concept the industrial partners and Upper Austria University of Applied Sciences implement the academically developed mathematical analysis methods in real-life simulation and/or industrial use cases. A number of relevant test cases from the repositories of the partners, who are end-users, have been set up to compile an inventory. Next, the simulation results of the tools and algorithms developed within the project are compared against the results obtained with commercial and/or public domain tools already in use.

Speed-up of the chip design process

To enable future telecommunication systems to transmit enormous volumes of information over long distances, faster and more powerful IC designs are needed. "The key to enable the realisation of single-chip integration of high-GHz wireless modules is resolving the shortcomings in available design flows," states Hans-Georg Brachtendorf, Upper Austria University of Applied Sciences. "ICESTARS will introduce not only novel CAD tools but also the mathematical methods to deal with analogue/digital mixed signal simulation and future challenges in system design and methodologies. Our developments will boost Europe's RF-IC developers' attempt to remain at the top of the global telecommunication market."

Professor Dr Caren Tischendorf
Head of the Department of Mathematics/Computer Science

University of Cologne
Weyertal 86-90
50931 Cologne
Germany

Tel: +49 221 470 6080
Fax: +49 221 470 6076

tischendorf@math.uni-koeln.de
www.icestars.eu